SUPPORTING DOCUMENT H

TECHNICAL MEMORANDUM

Construction Site Sediment and Total Phosphorus Loading

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Introduction

Chesterfield County staff and residents are concerned that the extensive planning involved with managing the Upper Swift Creek Reservoir watershed will be rendered ineffective by large amounts of construction-related sediment and associated total phosphorus (TP). During a previous study of the watershed, the Watershed Management Master Plan and Maintenance Program for the Swift Creek Reservoir Watershed (CH2M HILL, 2000), a simple modeling exercise was used to estimate the annual construction sediment and phosphorus load to the reservoir. The results indicated up to 8,000 tons per year of sediment and 798,000 pounds per year of TP could be released by construction activities.

CH2M HILL has been contracted to conduct a more refined assessment of construction-related loads within the reservoir. The purpose of this technical memorandum (TM) is to describe the approach to and the results of estimating sediment load and TP load generated by construction activity within the Upper Swift Creek Reservoir watershed in Chesterfield County, Virginia. The assessment was conducted in three main steps.

1. Compute soil loss for two pilot sites, with and without erosion and sediment control, and determine average annual soil loss per acre based on the results from the two pilot sites
2. Apply the average annual soil loss to the Swift Creek Reservoir watershed based on land anticipated to be developed within each tributary watershed
3. Determine sediment load delivered to Swift Creek Reservoir based on standard sediment delivery ratios and extrapolate the associated TP load

The result of this analysis was an estimation of the annual amount of sediment and TP reaching the reservoir from construction-related activities.

The remainder of this TM describes the three steps in the analysis, the results, and provides conclusions about how these results impact the previous watershed management plans.

Soil Loss

Pilot Sites

Two pilot sites were selected by the County to represent the range of development potential within the reservoir watershed. Figure 1 shows the locations of the two pilot sites.

The Cosby Road High School site is a 63-acre site dedicated to a high school and associated support facilities. It was selected to represent typical commercial and institutional sites, where significant site grading would be required to create level land needed for the facility. The site was modified to reduce the existing 5 to 10 percent slopes to nearly flat slopes for use in constructing the school and associated parking lots and sport fields.

The Millcrest at the Brandermill site is an 8-acre section of an existing subdivision. It was selected as a representative plan for residential development. Site grading is limited to creating roads and infrastructure, with limited modification to the residential lots.

Soil Loss Computations

Soil loss during construction was computed using the Revised Universal Soil Loss Equation, Version 2 (RUSLE2), a computer program developed by the U.S. Department of Agriculture – -Agricultural Research Service and Natural Resource Conservation Service (NRCS) to estimate soil erosion due to rainfall and runoff. The program was developed to examine erosion due to agricultural activities; however, it is also applicable to construction activity due to the significant land disturbance involved. RUSLE2 is frequently used to estimate erosion for preparing erosion and sediment control plans for construction sites.

FIGURE 1
Location of Pilot Sites

RUSLE2 is based on the USLE equation, and automates the computation of coefficients reflecting regional climate, land slope, slope length, soil type, and land management, as follows:

$$a_i = r_i k_i l_i S c_i p_i$$

where, all on the *ith* day:

$\mathbf{a_i}$ = average annual soil loss
$\mathbf{r_i}$ = erosivity factor
$\mathbf{k_i}$ = soil erodibility factor
$\mathbf{l_i}$ = soil length factor
S = slope steepness factor
$\mathbf{c_i}$ = cover-management factor
$\mathbf{p_i}$ = supporting practices factor

Land slope and slope lengths were computed for each drainage area defined in the erosion and sediment control plan. Both existing and proposed slopes were evaluated to determine the range of soil loss rates. The drainage areas, slope lengths, and slope steepness for each subbasin for the two pilot sites are summarized in Appendix A. According to the construction plans, the soils at the Millcrest site are dominated by Mayodan gravelly sandy loam at a 12 to 20 percent slope (soil type 151D). Based on the site location and County soil maps, the soils at the Cosby Road High School site are dominated by Mayodan gravelly sandy loam at a 2 to 6 percent slope (soil type 151B).

County-specific climate and soils data were available from the NRCS online database (NRCS, 2005) and are directly accessed by the RUSLE2 computer program. Land management parameters are associated with conservation tillage and crop rotation activities. These are not applicable to construction activities, as land is assumed to be bare during construction. The default construction management inputs were selected, which equate to no vegetation or conservation activities (c_i=1, p_i=1). Erosion and sediment controls were considered in a separate analysis.

The results from RUSLE2 for the two pilot sites indicate that the average annual soil loss rate will range from 7 to 33 tons per acre per year. The results for individual drainage areas for both proposed and existing site grading are provided in Appendix A. The results of this first step assume that the entire site is disturbed throughout the year and that no erosion and sediment control practices were used.

Erosion and Sediment Control

The sediment control devices proposed on the two pilot construction sites included sediment basins and sediment traps. Literature values from the Center for Watershed Protection were used to determine the percent removal of sediment from the runoff. These values are summarized in Table 1 for the two practices used on the pilot sites, and several additional practices for reference.

The reported average percent reduction was applied to the soil loss from the drainage area served by each device and summed to determine the total sediment load discharged from each site with sediment controls. The reduced soil loss rate ranges from 2 to 13 tons per acre per year, when sediment control devices are included. The results of individual drainage areas for both proposed and existing site grading are provided in Appendix A.

Other potential sediment control devices that could be considered include silt fence and hay bales. These were not proposed on the pilot sites and are not included in this analysis. These devices are typically used on small areas of disturbance, but tend to be less effective than sediment basins and traps. Although these devices can have significant localized impacts, it was assumed that from a watershed basis, the variation resulting from these devices was within the range of uncertainty of the results.

Erosion controls include temporary seeding of dormant areas, tarps over staging piles, and sod or seeding of completed grading. It was determined that the most effective means of approximating the impacts of erosion control measures was in the amount of time over which land was assumed to be bare, which was taken into account in the extrapolation of soil loss rates to the watersheds.

TABLE 1
Percent Reduction in Sediment Load Due to Erosion and Sediment Controls

Device	Low	High	Average
Sediment Basin	55	100	70
Sediment Trap	-7	100	60
Filter Fabric Fence	0	100	70
Vegetative Filter Strip	20	80	70
Seeding (after vegetative establishment)	50	100	90
Sod	98	99	99

Source: EPA, 1993

Sediment and Total Phosphorus Delivery

Sediment Delivery

Once the annual soil loss rate was calculated for 1 acre of land disturbed for an entire year, the results could be applied to construction throughout the watershed. Developable area was calculated for each tributary watershed based on the existing 2004 land use and the build-out land use plans developed to assess the future Upper Swift Creek Land Use Plan.

Annual average area disturbed was calculated by dividing developable area by the period of development, 25 years. Average sediment load was then calculated by multiplying the annual area disturbed by the soil loss rates calculated in Section 2 and by the fraction of the year a typical area remains disturbed. A factor of 0.75 was used in this analysis, meaning the typical area is disturbed for 9 months. Table 2 summarizes the annual area disturbed and resulting soil loads for each tributary watershed.

TABLE 2
Total Sediment Load from Proposed Development by Tributary Watershed
Upper Swift Creek Plan Modeling Support

Tributary Watershed	Total Area Disturbed (ac/yr)	Annual Average Area Disturbed (ac/yr)	Annual Sediment Load no ESC (ton/yr)	Annual Sediment Load with ESC (ton/yr)
Little Tomahawk Creek	1,229	49.2	260 – 1,220	80 - 490
Tomahawk Creek	2,017	80.7	420 – 2,000	140 - 800
Swift Creek / Turkey Creek System	4,640	185.6	970 – 4,600	310 – 1,840
Otterdale Creek	1,543	61.7	320 – 1,530	100 – 610
Blackman Creek / Horsepen Creek / Deep Creek System	5,446	217.8	1,140 – 5,400	370 – 2,160
Dry Creek	1,044	41.8	220 – 1,040	70 – 410
West Branch	674	26.9	140 – 670	50 – 270
Fuqua Creek	769	30.7	160 – 760	50 – 300
Direct Runoff Component	947	37.9	200 – 940	60 – 380
Total	**18,310**	**732.4**	**3,830 – 18,160**	**1,230 – 7,260**

Notes:
Total area disturbed is for Chesterfield County only. Land disturbance upstream in Powhatan County is not included in this study.
ESC = erosion and sediment controls

The average sediment load is the sediment leaving disturbed areas in construction sites. It is not the amount of sediment reaching the reservoir. A large percentage of the sediment load that is dislodged from the land is removed from the tributary flow prior to reaching the reservoir, primarily due to settling during overland and in-channel flows. One method of determining the fraction of sediment load that reaches the reservoir is the application of a sediment delivery ratio (SDR). The SDR used for this study is based on the NRCS National Engineering Handbook (SCS, 1983). Section 3, Chapter 6 of the National Engineering Handbook presents the SDR as a curve in Figure 6-2. A recent study by U.S. Environmental Protection Agency (EPA) Region 4 (Greenfield, 2001) converts the curve to the following formula:

$$SDR = 0.417762A^{-0.134958} - 0.127097$$

where A is the watershed area in square miles.

Most of the reservoir's tributaries drain directly to the reservoir and are independent of each other. The best approach to determine the portion of sediment load that reaches the reservoir is to calculate separate SDRs for each tributary. Turkey Creek is included in the Swift Creek system. Blackman Creek is included in the Horsepen Creek/ Deep Creek system. Table 3 includes the tributary watershed areas and their corresponding SDRs. Note that the Swift Creek system only includes that part of the watershed within Chesterfield County.

Applying the tributary SDRs to the average sediment dislodged from the surface results in the sediment loads that are predicted to be delivered to the reservoir each year. These loads are included in Table 4.

TABLE 3
Tributary Watershed Sediment Delivery Ratios
Upper Swift Creek Plan Modeling Support

Tributary Watershed	Drainage Area (sq. miles)	SDR
Little Tomahawk Creek	3.70	0.223
Tomahawk Creek	5.67	0.203
Swift Creek / Turkey Creek System	21.76	0.149
Otterdale Creek	3.86	0.221
Blackman Creek / Horsepen Creek / Deep Creek System	11.58	0.173
Dry Creek	3.06	0.232
West Branch	2.90	0.235
Fuqua Creek	2.38	0.245
Direct Runoff Component	7.03	0.194

As an example, this paragraph carries a single watershed through the analysis. Dry Creek is predicted to have 1,044 acres of developed land, which equates to an average of 41.8 acres of land developed per year over the 25-year development horizon. Of this, 41.8 acres times 33.06 ton/ac/yr without erosion and sediment control (ESC) times 0.75 (the portion of year land disturbed) results in 1,036 tons of sediment dislodged from the surface. Using the SDR for Dry Creek, 1,036 tons per year times 0.232 results in 240 tons of sediment delivered to Swift Creek Reservoir per year.

TABLE 4
Sediment Delivery to Upper Swift Creek Reservoir
Upper Swift Creek Plan Modeling Support

Tributary Watershed	Sediment Delivery no ESC (ton/yr)	Sediment Delivery with ESC (ton/yr)
Little Tomahawk Creek	60 – 270	20 – 100
Tomahawk Creek	90 – 410	30 – 160
Swift Creek / Turkey Creek System	140 – 680	50 – 270
Otterdale Creek	70 – 340	20 – 140
Blackman Creek / Horsepen Creek / Deep Creek System	200 – 930	60 – 370
Dry Creek	50 – 240	20 – 100
West Branch	30 – 160	10 – 60
Fuqua Creek	40 – 190	10 – 70
Direct Runoff Component	40 – 180	10 – 70
Total	720 – 3,400	230 – 1,350

Phosphorus Delivery

Sediment in runoff is a known source of TP. If one can determine the relationship between sediment and TP, then the construction sediment loads delivered to the reservoir can be used to predict the accompanying TP load. The Chesterfield Department of Utilities has established in-stream monitoring stations for each of the main tributaries. These monitoring stations are typically located in the lower part of each tributary watershed, in a reach that has little or no influence from reservoir tailwater.

CH2M HILL used the monitoring data collected from 1974 to 1997 to calculate the ratio between total suspended solids (TSS) and TP. The average TSS/TP ratio was calculated from wet weather flow data from the nine monitoring stations. Base flow data was not included in the calculations. The average TSS/TP ratio was 1,009. The resulting TP loads delivered to the reservoir is summarized in Table 5.

TABLE 5
Total Phosphorus Delivery by Tributary Watershed
Upper Swift Creek Plan Modeling Support

Tributary Watershed	TP Delivery no ESC (lb/yr)	TP Delivery with ESC (lb/yr)
Little Tomahawk Creek	120 – 540	40 – 220
Tomahawk Creek	180 – 810	60 – 320
Swift Creek / Turkey Creek System	280 – 1350	100 – 540
Otterdale Creek	140 – 670	40 – 280
Blackman Creek / Horsepen Creek / Deep Creek System	400 – 1840	120 – 730
Dry Creek	100 – 480	40 – 200
West Branch	60 – 320	20 – 120
Fuqua Creek	80 – 380	20 – 140
Direct Runoff Component	80 – 360	20 – 140
Total	1,440 – 6,750	460 – 2,690

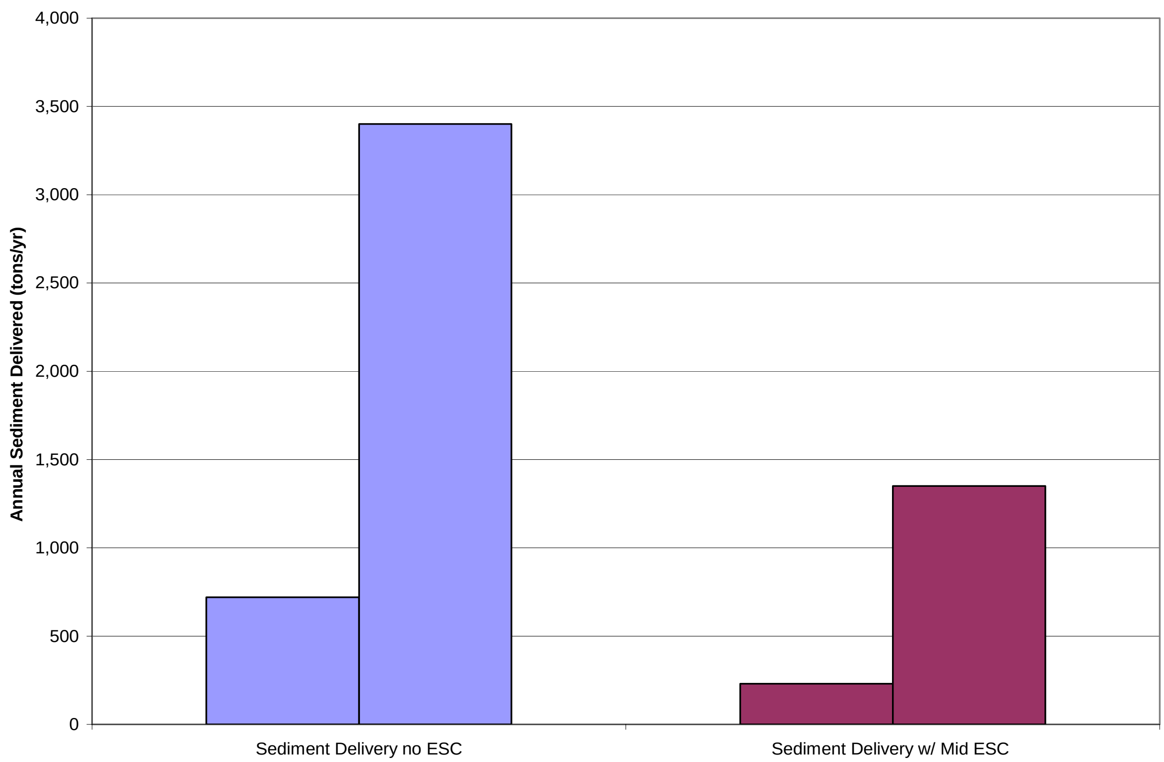
Conclusion

A typical year in the watershed could see the delivery of 720 to 3,400 tons per year of sediment from unprotected construction sites. Erosion and sediment controls are predicted to reduce the annual load to between 230 and 1,350 tons per year. The actual load reaching the reservoir is probably somewhere between the two ranges. This is due to a number of factors, including portions of projects that are not protected by erosion and sediment controls, the challenge of properly maintaining the control facilities, and the occurrence of larger storms that exceed the design capacity of the controls. The amount of sediment predicted to reach the reservoir is significantly less than the 8,000 tons per year, as estimated in 1999. The differences between the two estimates can be explained by different techniques, development periods, and TSS/TP ratios.

If the County can maintain good erosion and sediment controls, then the predicted TP delivery to the reservoir is 460 to 2,780 pounds per year. The Management Plan and updated modeling both point to the required goal in the range between 25,000 and 26,000 pounds of TP per year at projected build out of the watershed. In terms of annual TP loading goal, the TP associated with construction sediment is approximately 2 to 11 percent of the annual goal for the reservoir. Without erosion and sediment controls, the range is 1,500 to 6,970 pounds per year, or approximately 6 to 27 percent of the annual goal.

Based solely on annual loading rates, the current assimilative capacity of the reservoir should be able to accommodate the additional TP from construction sites if erosion and sediment controls are properly installed and maintained (Figure 2). In time, this could become an issue if erosion and sediment controls are not properly installed. However, the timely establishment of the BMPs identified in the Management Plan will further reduce the construction site TP load reaching the reservoir.

FIGURE 2
Summary of Annual Sediment Loads Due to Construction
Upper Swift Creek Reservoir Watershed Management Plan



One issue that has not been examined to date is the impact of the sediment that settles to the bottom of the reservoir. Based on the annual TP loading rate and annual volume of runoff, the Reckhow Model does not explicitly calculate the cumulative effects of the sediment and associated TP deposited on the bottom of the reservoir. This sediment will be a potential TP source for years to come, particularly as the reservoir stratifies each summer.

Another issue to consider is stream health. The sediment delivery ratios for each of the tributary watersheds range from 17 to 25 percent. The converse is that 75 to 83 percent of the sediment leaving construction sites does not reach the reservoir and is instead deposited during overland flow, and largely on stream bottoms. The result is a probable loss of habitat for many of the benthic macroinvertabrates and other fauna.

The County's Watershed Assessment and Stream Protection Program (WASP) is dedicated to "preserve, protect, and restore the ecological integrity of the County's streams and other water resources." The portion of the sediment load deposited in the tributaries will require additional management from the WASP.

References

CH2M HILL. 2000. Watershed Management Master Plan and Maintenance Program for the Swift Creek Reservoir Watershed, Chesterfield County, Virginia. May.

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Appendix A

TABLE A-1
Milcrest RUSLE2 Input Data and Results
Upper Swift Creek Plan Modeling Support

Existing Condition

	Area, ac	Slope Length, ft	Slope, ft/ft	Soil Loss Rate, Tons/Ac/Yr	Soil Loss, Tor
ST-1	2.3	180	0.100	35	81
ST-2	2.8	250	0.088	32	90
ST-3	1.3	190	0.094	32	42
ST-4	1.5	150	0.100	33	50
Total	**7.9**			**33**	**261**

Proposed Condition

	Area, ac	Slope Length, ft	Slope, ft/ft	Soil Loss Rate, Tons/Ac/Yr	Soil Loss, Tor
Area A	1.08	130	10.4	33	36
Area B	0.66	150	8.7	26	17
Area C	1.4	158	8.9	27	38
Area D	0.85	170	7.4	23	20
Area E	0.52	160	6.3	18	9
Area F	1.34	120	9	25	34
Area G	0.3	50	10	22	7
Area H	0.3	60	10	23	7
Area I	0.27	20	10	16	4
Area J	0.35	30	10	18	6
Total	**7.07**			**25**	**177**

Range across site conditions w/o ESC	25 to 33
Range across site conditions w/ ESC	0 to 35
Average across site conditions w/o ESC	29.1
Average across site conditions w/ ESC	12

TABLE A-2
Cosby High School RUSLE2 Input Data and Results
Upper Swift Creek Plan Modeling Support

Existing Conditions

	Area, ac	Slope Length, ft	Slope, ft/ft	Soil Loss Rate, Tons/Ac/Yr	Soil Loss, Tons/yr	E&SC TSS Removal, % (Avg)	Soil Loss w/ ESC (Mid)
SB1	8.05	490		26	209	70	63
SB2	5.69	670	0.051	21	119	70	36
SB3	9.55	535	0.080	36	344	70	103
SB4a	8.33	480	0.054	21	175	70	52
SB4b	4.16	230	0.087	30	125	70	37
SB5	9.85	450	0.100	26	256	70	77
ST1	1.50	290	0.079	29	44	60	17
ST2	2.00	340	0.077	30	60	60	24
ST3	1.80	170	0.073	22	40	60	16
ST4	1.30	190	0.071	22	29	60	11
ST5	1.50	340	0.035	12	18	60	7
ST6	1.80	280	0.060	20	36	60	14
ST7	1.49	290	0.088	34	51	60	20
ST8	0.80	200	0.075	26	21	60	8
Total	**57.82**			**26**	**1526**	**ton/yr**	**487**
						ton/ac/yr	**8**

Proposed Conditions

	Area, ac	Slope Length, ft	Slope, ft/ft	Soil Loss Rate, Tons/Ac/Yr	Soil Loss, Tons/yr	E&SC TSS Removal, % (Avg)	Soil Loss w/ ESC (Mid)
SB1	5.90	400	0.038	13	77	70	23
SB2	3.46	180	0.019	5	17	70	5
SB3	11.24	380	0.017	4.9	55	70	17
SB4a	10.60	390	0.034	12	127	70	38
SB4b	5.30	260	0.023	6.7	36	70	11
SB5	7.48	160	0.013	3.3	25	70	7
ST1	2.90	230	0.015	4	12	60	5
ST2	2.90	230	0.015	4	12	60	5
ST3	2.90	490	0.020	6.2	18	60	7
ST4	2.00	170	0.020	5.3	11	60	4

TABLE A-2
Cosby High School RUSLE2 Input Data and Results
Upper Swift Creek Plan Modeling Support

Proposed Conditions

	Area, ac	Slope Length, ft	Slope, ft/ft	Soil Loss Rate, Tons/Ac/Yr	Soil Loss, Tons/yr	E&SC TSS Removal, % (Avg)	Soil Loss w/ ESC (Mid)
ST5	2.00	260	0.014	3.7	7	60	3
ST6	1.39	300	0.028	8.7	12	60	5
ST7	1.50	80	0.029	7	11	60	4
ST8	1.50	30	0.033	6.5	10	60	4
ST9	2.00	420	0.020	6.1	12	60	5
Total	**63.07**			**7.0**	**440**	**ton/yr**	**142**
						ton/ac/yr	**2**

Range across site conditions w/o ESC	7 to 26	T/Ac/y
Range across site conditions w/ ESC	0 to 15	T/Ac/yr
Average across site conditions w/o ESC	17	T/Ac/y
Average across site conditions w/ ESC	5	T/Ac/yr